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PROPANE FLEET TEST

MANITOBA TELEPHONE SYSTEM

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MANITOBA/CANADA CONSERVATION AND RENEWABLE ENERGY DEMONSTRATION AGREEMENT

The availability of secure and affordable energy supplies is a subject of national concern. It is an accepted fact that our primary energy sources - oil and natural gas - are becoming less accessible and more costly. However, Canada is well-endowed with non-renewable and alternative resources that can provide a bridge into the future.

To this end, the governments of Manitoba and Canada have entered into a Conservation and Renewable Energy Demonstration Agreement which was signed May 9, 1980 and terminates March 31, 1984. The Agreement is dedicated to the development and demonstration of conservation and renewable energy technologies. Equally cost-shared by the provincial and federal governments, the program has a total budget of $18 million.

The objectives of CREDA are:

- To develop and demonstrate promising new technologies, which, when widely adopted, will exploit renewable resources, conserve energy and/or use energy more efficiently.

- To develop broad public awareness of the potential of renewable energy and conservation technology.

- To provide opportunities for the commercial application of the technologies within Manitoba.

- To create economic spin-off benefits for manufacturing, industry and commerce.

- To create employment in new or existing energy-related industries.

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1.0 EXECUTIVE SUMMARY

1.1 This fleet test was funded under the Manitoba/Canada Agreement for the Development and Demonstration of Renewable Energy and Energy Conservation Technologies. The objective of the test was to assess the feasibility of propane as an automotive fuel in Manitoba, by comparing the overall performance and operating costs of a test fleet operating on propane with that of a control fleet operating on unleaded gasoline.

1.2 The test and control fleets each consisted of 25 vehicles taken from the existing Manitoba Telephone System fleet of service vehicles. Each fleet was composed of a selection of similar vehicle pairs ranging from subcompact automobiles with a mass of 1160 kg to bulk tankers with a mass of 12700 kg. Engine displacements varied from 1.57 to 6.55 L.

1.3 During the two year test period, the propane fleet travelled about 750,000 km while the gasoline control fleet travelled about 1,000,000 km.

1.4 The grade HD5 propane used in the test fleet was dispensed to the fleet vehicles through Manitoba Telephone System's own facilities. Periodic assessment of the propane fuel was conducted by the propane supplier, Petrocan Ltd. The energy content of the propane fuel ranged from 26.9 to 27.2 MJ/L.

1.5 The performance of gasoline and propane was compared by using two specific types of tests: General driveability and relative fleet fuel consumption were determined by driver surveys and gross fuel use data from normal urban and rural vehicle operation. Specific fuel consumption was determined by controlled chassis dynamometer tests on a series of selected vehicles utilizing representative driving cycles.

1.6 Specific test results are as follows:

(a) Driveability: Fleet drivers operating propane fueled vehicles were satisfied with vehicle operation and reported similar vehicle performance with either gasoline or propane. In most cases, the same drivers operated the same vehicles before and after conversion to propane.

(b) Relative Fleet Fuel Consumption: Because of limited propane availability during the test, the gasoline control fleet was operated primarily in rural areas, while the propane test fleet was operated primarily in two urban areas. As a result, comparison of overall fleet fuel consumption data for the two fleets was not valid.

To permit a comparison of overall fleet fuel consumption, the specific fuel consumption of each of the 25 propane vehicles was compared to the specific fuel consumption of each of these vehicles, when operating on gasoline, for the 12 month period before initiation of the fleet test. In both cases, operation was in urban areas.

Although there was no significant difference in specific fuel consumption the specific energy consumption of similar vehicles was lower when operated on propane, than when operated on gasoline. Significant at the 90% confidence level, this difference in specific energy consumption varied from 65.1 to 245.1 MJ/100 km.

(c) Chassis Dynamometer Tests: Chassis dynamometer tests, comparing six different pairs of vehicles operating alternately on gasoline and propane were conducted at load conditions simulating urban driving at 48 km/h and highway driving at 88 km/h. These tests eliminated the many uncontrolled variables that occur in fleet comparisons, permitting a valid comparison of specific fuel consumption of similar vehicles operating on propane and gasoline in urban and highway driving conditions. Specific fuel consumption for the propane vehicles was significantly greater than for the gasoline vehicles in both urban and highway driving conditions. Because of the difference in specific fuel costs of the two fuels, however, cost savings occurred when using propane. These savings ranged from 34% in urban driving to 32% in highway driving.

1.7 Overall test results indicated that propane is a viable fuel alternative to gasoline. On a cost basis of 23.5¢/L for propane and 43.9¢/L for gasoline resulting in a price spread of 20.4¢/L between gasoline and propane, the fleet operator should realize approximately 30% savings in fuel costs.

1.0 SOMMAIRE

1.1 Cet essai a été financé dans le cadre de l'Entente Canada-Manitoba de démonstration des économies d'énergie et des énergies renouvelables (CREDA) lancée en 1980 par le gouvernement du Manitoba et le gouvernement fédéral. Ce programme bénéficie d'un budget total de 18 millions de dollars auquel contribuent à part égale les deux paliers de gouvernement. Ce programme a pour raison d'être de faciliter le développement de nouvelles technologies qui favoriseront la conservation de l'énergie et l'exploitation des ressources énergétiques renouvelables. Parmi les objectifs importants du programme, mentionnons la sensibilisation du public, la découverte d'applications commerciales, la création de retombées économiques pour l'industrie manitobaine et la stimulation de l'emploi.

Cet essai avait pour objectif d'évaluer la rentabilité du propane au Manitoba en comparant le rendement global et les coûts d'exploitation d'un parc-pilote fonctionnant au propane avec ceux d'un parc de contrôle alimenté en essence sans plomb. Les fonds fournis au terme du CREDA se sont élevés à 111 000 $, tandis que la Société de téléphone du Manitoba a consenti pour sa part la somme de 60 250 $.

1.2 Le parc-pilote et le parc de contrôle étaient tous deux constitués de 25 véhicules choisis parmi les véhicules d'entretien du parc actuel de la Société de téléphone du Manitoba. La composition de ces deux parcs était identique quant à la nature des véhicules, allant des automobiles sous-compactes d'une masse de 1 160 kg aux camions citernes pesant 12 700 kg. Les cylindrées variaient de 1,57 litre à 5,74 litres.

1.3 L'essai s'est déroulé pendant 2 ans, période au cours de laquelle les véhicules du parc-pilote alimentés en propane ont parcouru 7 500 km, alors que le parc de contrôle fonctionnant à l'essence sans plomb avait à son actif 1 000 000 de km.

1.4 Le propane de qualité HD5 employé pour alimenter les véhicules du parc-pilote était dispensé dans les installations de la Société de téléphone du Manitoba. Des analyses périodiques du propane ont été effectuées par le fournisseur, Petrocan Ltée. La valeur énergétique du propane oscillait entre 26,9 et 27,2 MJ/L.

1.5 Les rendements conférés par l'essence et par le propane ont été comparés par le biais de deux types d'essais distincts: La souplesse générale de conduite et la consommation relative de combustible ont été établies grâce à des sondages auprès des conducteurs et à des données de consommation portant sur l'utilisation normale des véhicules en ville ou à la campagne. La consommation spécifique de carburant a été établie par des essais dynamométriques effectués sur des véhicules choisis et reproduisant des cycles de conduite type.

1.6 Les résultats des différents essais se présentent comme suit:

(a) Souplesse de conduite: Les conducteurs des véhicules alimentés en propane se sont dits satisfaits du comportement de leurs véhicules et ont signalé que le rendement restait essentiellement le même quelque soit le carburant employé. Dans la majorité des cas, les conducteurs étaient affectés aux mêmes véhicules avant et après la conversion au propane.

(b) Consommation comparée des deux parcs: Le propane n'étant disponible qu'en quantité limitée durant la période d'essai, il a été décidé de déployer le parc de contrôle (essence) principalement à la campagne, et d'exploiter le parc-pilote (propane) en ville surtout, plus précisément dans deux zones urbaines.

Pour obtenir des résultats utilisables dans le cadre de l'essai, on a comparé la consommation spécifique de chacun des 25 véhicules du parc-pilote avec la consommation spécifique de ces mêmes véhicules au cours des 12 mois précédant leur conversion, c'est-à-dire lorsqu'ils fonctionnaient à l'essence. Dans les deux cas, les véhicules étaient exploités en ville.

Bien qu'il n'y avait aucune différence sensible de consommation de carburant, la consommation spécifique de véhicules semblables était moindre dans le cas des véhicules fonctionnant au propane que dans celui des véhicule alimentés en essence. Cette différence, au niveau de confiance de 90 p. 100, variait de 65,1 à 245,1 MJ/100 km.

(c) Essais dynamométriques du véhicule: Les essais dynamométriques du véhicule, employés pour comparer le rendement de six paires de véhicules différents alimentés en essence puis en propane, se sont déroulés dans des conditions de charge simulant la conduite en ville à 48 km/h et la conduite sur route à 88 km/h. Cette façon de procéder a permis de supprimer les variables aléatoires qui faussent inévitablement les comparaisons entre parcs de véhicules et d'aboutir à une comparaison valable de la consommation spécifique de véhicules semblables fonctionnant au propane et à l'essence, en ville et sur la route. La consommation spécifique des véhicules du parc-pilote (propane) était sensiblement supérieure à celle des véhicules du parc de contrôle, en ville et à la campagne. Toutefois, en raison de la différence de prix de ces deux carburants, le propane a permis de réaliser des économies qui allaient de 34 p. 100 en ville à 32 p. 100 sur la route.

1.7 Il ressort de tous ces essais que le propane constitue un combustible de remplacement tout à fait viable. Si le propane se vend à 23,5 ¢/L et l'essence à 43,9 ¢/L, ce qui donne une différence de 20,4 ¢/L, il est probable que la conversion au propane permettrait à un exploitant de parc de véhicules de réaliser des économies de l'ordre de 30 p. 100 sur les coûts d'exploitation.

2.0 INTRODUCTION

This fleet test was conducted by the Manitoba Telephone System under a joint contract from the Canadian Department of Energy, Mines and Resources and the Manitoba Department of Energy and Mines through the Manitoba/Canada Agreement for the Development and Demonstration of Renewable Energy and Energy Conservation Technologies. The Industrial Technology Centre/Manitoba Research Council was retained as the technical consultant, providing project supervision, data analyses, testing services and report preparation.

The objective of the test was to assess the feasibility of propane as an automotive fuel in Manitoba by comparing the overall performance and operating costs of a test fleet operating on propane with that of a control fleet operating on unleaded gasoline. The large variations in temperature and climatic extremes, typical to Manitoba, make it an ideal location for this type of fuel comparison testing.

Test vehicles were selected from the existing Manitoba Telephone System fleet of service vehicles. The propane powered test fleet and the gasoline powered control fleet each consisted of 25 similar vehicles ranging from subcompact automobiles with a mass of 1161 kg to panel trucks with a mass of 5448 kg. Corresponding engine displacements varied from 1.57 to 5.74 L. Five heavy vehicles (i.e. tank truck, diggers, etc.) were added to the propane fleet. There were no comparable control vehicles for these five propane powered vehicles.

The propane fleet demonstration was initiated December 1, 1980 and continued until November 30, 1982.

Several significant test program changes were initiated by the program advisory committee during the test, as a result of ongoing test results and recommendations from the technical consultant. Original program plans were to utilize fuel consumption data from the two fleets in actual operation to compare specific fuel consumption. The large data scatter, typically associated with field tests, as a result of many uncontrolled variables, invalidated this type of fuel consumption comparison. It was therefore, concluded that fleet data were valid only for general driveability comparisons.

During the 24 month test period, the propane test fleet travelled a cumulative distance of 750,000 km while the gasoline control fleet travelled about 1,000,000 km. This report summarizes the results of all work conducted during the test period and details test procedures as well as modifications to procedures needed to meet program objectives. It also describes methods of data analysis needed to determine the significance of relatively small differences in performance of the two fleets and recommends procedures that should be considered as key components of future fuel comparison testing. Due to the large amount of raw data collected only representative data samples or sumnary tables are included in this report.

3.0 SCOPE AND OBJECTIVES

3.1 Objectives

The overall objectives of the fleet test were as follows:

(a) To assess the driveability and overall performance of automotive vehicles operated on propane, in Manitoba driving conditions, relative to the performance of similar vehicles operated on gasoline.

(b) To compare the specific fuel consumption and operating costs of fleets of similar vehicles operating on propane and gasoline.

3.2 Scope of Work

The following work was conducted to achieve program objectives:

(a) Throughout the tests, vehicle performance data were analyzed with the MAINSTEM[1] data analysis system.

(b) Statistical techniques were developed for ongoing performance comparison of the propane and control fleets. These included comparisons of specific fuel consumption and specific energy consumption of the propane fleet with that of paired vehicles in the control fleet and with historic data on the propane vehicles prior to conversion to propane. Paired significance tests were also conducted on chassis dynamometer data comparing vehicle performance on gasoline and propane.

(c) Six representative vehicles from the propane fleet were tested on a chassis dynamometer utilizing simulated urban and highway driving cycles. Tests were conducted with similar vehicles fueled with gasoline to enable fuel consumption comparisons in similar controlled driving conditions.

(d) Throughout the test period, general vehicle driveability was evaluated by having all operators of the propane fleet complete a daily vehicle performance sheet. Driveability assessments were based on analysis of vehicle data sheets as well as vehicle service history records maintained by Manitoba Telephone System.

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[1]MAINSTEM Data system, Willowdale, Ontario. MAINSTEM is a commercial, computer-based accounting system for compilation and simple analysis of fleet performance data.

4.0 METHODS AND TEST PROCEDURES

4.1 Fleet Vehicle Selection and Operation

It was proposed that a fleet of 50 vehicles be used for the propane fuel demonstration. The fleet consisted of a variety of vehicles, including subcompact automobiles with a mass of 1161 kg to panel trucks and tankers with a mass of 12700 kg. Engine displacements varied from 1.57 to 6.55L. All vehicles were brought up to manufacturers specifications by MTS personnel prior to the start of the program. The propane vehicles required modification to the fuel system. This entailed replacing the fuel tank and the carburetion system. Once converted the propane vehicles could not operate on other liquid fuels.

Due to vehicle availability and MTS service priority, a total of only fifteen identical pairs of vehicles could be obtained for the two fleets. The remaining unmatched vehicles were included to test the viability of propane fuel compared to unleaded gasoline under a variety of driving conditions.

At the start of the demonstration it was believed that the two fleets, although operating in different areas, operated under essentially the same conditions. However, by close examination of initial test results and historic data, it was learned that the driving conditions, although similar were not the same. The propane fleet was operated in the City of Winnipeg due to the unavailability of propane in rural areas. For logistic reasons the control fleet operated in rural communities. It was therefore decided that the test data would be compared with the historic data and the control fleet would be retained to allow driveability and maintenance requirements to be compared. The matched and unmatched vehicles are listed in Tables 1 and 2.

The propane demonstration lasted 24 months in which the propane test fleet travelled for a cumulative distance of 750,000 km, while the gasoline control fleet travelled about 1,000,000 km.

4.2 Vehicle Conversion

For operation on propane fuel, Impco conversion kits were installed on the 25 vehicles. After conversion these vehicles were dedicated to operate on propane fuel only. No other modifications were made to the engines. Suitable high pressure tanks were installed for storage of the liquid propane. The propane fleet vehicles were converted according to installation code #CAN1-B149.2-73.

Table 1. Matched Fleet Vehicles

Vehicle Type	Year	Model	Gross Vehicle Mass(kg)	Engine Displacement (L)	Number of Cylinders	Transmissions	Fuel
1	1980	Ford Van	2520	4.92	6	Standard	P,G
2	1979	Chevrolet Blazer	2747	4.10	6	Standard	P,G
3	1979	Ford Pick up	3630	4.92	6	Standard	P,G
4	1979	Ford Van	2769	4.92	6	Standard	P,G
5	1979	Ford Van	2769	4.92	6	Standard	P,G
6	1979	Dodge Pick up	3405	3.69	6	Standard	P,G
7	1980	Dodge Pick up	3405	3.69	6	Automatic	P,G
8	1978	Chevrolet Van	2542	5.74	8	Automatic	P,G
9	1979	IHC Scout	2815	4.98	8	Automatic	P,G
10	1979	Chevrolet Pick Up	3405	5.74	8	Automatic	P,G
11	1979	Chevrolet Van	3587	5.74	8	Automatic	P,G
12	1979	Chevrolet Van	3587	5.74	8	Automatic	P,G
13	1978	Dodge Karry Van	4540	5.21	8	Automatic	P,G
14	1979	Chevrolet Step Van	5448	5.74	8	Standard	P,G
15	1980	Chevrolet Step Van	5448	5.74	8	Standard	P,G

P - propane fuelled (test fleet)
G - gasoline fuelled (control fleet)

Table 2. Unmatched Fleet Vehicles

Vehicle Type	Year	Model	Gross Vehicle Mass(kg)	Engine Displacement (L)	Number of Cylinders	Transmissions	Fuel
16	1979	AMC Concord	1820	3.80	6	Automatic	P
17	1980	Chevrolet Van	2730	4.10	6	Standard	P
18	1980	Chevrolet Van	2450	4.10	6	Standard	P
19	1980	Dodge Pick Up	2747	3.69	6	Standard	P
20	1979	Dodge Van Versalift	3720	5.21	8	Automatic	P
21	1980	Chevrolet Van	3630	5.74	8	Automatic	P
22	1980	Chevrolet TOW	7278	5.74	8	Standard	P
23	1978	Chevrolet Utility	7278	5.74	8	Standard	P
24	1978	Chevrolet Digger	10505	5.74	8	Standard	P
25	1978	IHC Bulk Tanker	12700	6.55	8	Standard	P
26	1978	Ford Fiesta	1161	1.57	4	Standard	G
27	1980	Mercury Zephyr Wagon	1835	2.29	4	Standard	G
28	1979	AMC Concord Wagon	2002	4.23	6	Automatic	G
29	1979	AMC Concord Wagon	2002	3.80	6	Automatic	G
30	1978	Ford Fairmont Wagon	1880	5.74	8	Standard	G
31	1980	Ford Fairmont Wagon	1936	3.28	6	Automatic	G
32	1980	Ford Fairmont Wagon	1880	3.28	6	Standard	G
33	1979	Dodge Pick Up	3405	5.21	8	Standard	G
34	1979	Chevrolet Van	2540	5.74	8	Automatic	G
35	1980	Chevrolet Van	3587	5.74	8	Standard	G

P - propane fuelled (test fleet)
G - gasoline fuelled (control fleet)

4.3 Driveability Assessment

Log sheets (Figure 1) were distributed to the fleet drivers. Vehicle operators were required to submit the log sheets on a weekly basis. Information collected from these sheets included distance travelled, amount of fuel consumed and the following list of driveability assessment factors:

1) The amount of cranking required to start engine
2) Stalling after starting
3) Stalling in traffic
4) Idle roughness
5) Hesitation, bucking or coughing
6) Lack of power

Driveability data were then tabulated and transcribed onto a bar graph.

4.4 Fuel Analyses

Periodic assessment of the energy content of the propane fleet was conducted by the propane supplier, Petrocan Ltd. Energy content of the test fuel ranged from 26.9 to 27.2 MJ/L.

4.5 Chassis Dynamometer Tests

Chassis dynomometer tests, comparing the performance of similar vehicles on both gasoline and propane were performed on a Sun Road-A-Matic chassis dynamometer at the Manitoba Telephone System test facility. Two test speeds (48 and 88 km/h) were used in the comparison. These speeds were chosen as they approximately simulated city and highway driving conditions and are also those recommended in the Sun specification manual.

The test at 48 km/h was characterized by a load producing a gauge pressure of -18.75 kPa at the intake manifold. At this condition, the throttle is sufficiently open to cause enough enrichment for cylinder pressure to be near maximum. This simulates city driving where a large proportion of the driving is acceleration and deceleration.

The test at 88 km/h was characterized by a load producing a gauge pressure of -57.2 kPa at the intake manifold. This is equivalent to cruising on a level road. Under these conditions the air/fuel mixture is lean and cylinder pressure is near minimum.

4.5.1 Test Procedure

Six vehicles from the propane fleet were tested by installing a fuel line to a 15 kg propane tank which rested on a digital Toledo scale. Testing proceeded only after the engine oil temperature had

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PROPANE - FLEET T[illegible]T

Daily Log Sheet

Vehicle No. _____ Type _____ Date _____

Vehicle Base Location _____ Driver's Name _____

Daily Distance
End: km _____

Starting: km _____

Services
Fuel Add:
L _____ Odomoter _____

Oil: # L _____

Tire Pressures
(Please check at least once a week)

Left Front _____ Right Front _____

Left Rear _____ Right Rear _____

Was vehicle refueled with other than test fuel? Yes _____ No _____. If Yes, please give fuel type and reason in Other Comments below.

Did you have problems with any of the following: If so, indicate severity.

	Mildly Annoying	Very Troublesome
1) Cranking required to start engine		
2) Stalled after starting		
3) Stalls in traffic		
4) Idle roughness		
5) Hesitation, bucking or coughing		
6) Lack of power		

Regardless of severity, if any problems occurred, please describe (1) type of driving, (2) time of occurence, and (3) approximate ambient temperature for each problem occurrence. _____

_____

_____

Other comments: _____

_____

Figure 1. Daily Log Sheet for Completion by Fleet Drivers

reached the minimum operating temperature. Dynamometer load settings were based on manifold gauge pressures -18.75 and -57.2 kPa at 48 and 88 km/h respectively. Once the appropriate load setting had been determined for a specific vehicle, engine power was used in the comparative tests, rather than manifold vacuum.

Gasoline was used as a fuel for the power determination for six comparable vehicles and was the first fuel tested. The gasoline test vehicles were run for 0.8 km at constant speed and power. The test was repeated 10 times per vehicle at both dynamometer speeds with fuel consumption recorded at the completion of each test. For propane vehicles, the procedure differed due to the difficulty in measuring the flow rate of propane. Propane fuel consumption was determined by weight. A propane tank was placed on a digital scale, accurate to $\pm$ 0.02 kg, and its weight recorded. Leaving the tank on the scale the vehicle was run for 3.6 km for the 48 km/h test and at the completion of the test the weight was recorded. The difference between the initial weight and the recorded weight was the fuel consumed. For the 88 km/h test, the distance was not fixed. The vehicle was run for a minimum of 3.6 km or until at least 0.45 kg of fuel was consumed. Each test was repeated 5 times. The propane tests were run at the same power setting as the gasoline tests. For comparison purposes, the weight of propane consumed was converted to volume at ambient conditions.

The test work employed two vehicle operators. However, to ensure consistency only one operator was used on each specific vehicle.

4.6 Data Analysis

4.6.1 MAINSTEM Data Collection System

MAINSTEM is a commercial, computer-based accounting system for the compilation and analysis of fleet data. It is generally used by fleet managers to track fleet costs and vehicle maintenance. This system was used for monitoring the fuel consumption of the propane and control fleets.

4.6.2 Paired Significance Tests

Initial attempts to compare fuel consumption data from the two fleets independently, were rejected as statistically unacceptable since the propane fleet was operated primarily in an urban environment and the gasoline fleet was operated primarily in a rural environment.

Therefore the fuel consumption data collected for the propane fleet were compared with historic data (data for the 12 months prior to the propane demonstration) for the same vehicles. In this manner, it was possible to compare the performance of identical vehicles with two different fuels under relatively similar operating conditions.

A paired significance test was performed with the above data[2,3]. The data were also analyzed for possible relationships between energy consumption and vehicle mass.

Similar paired significance tests were also performed comparing specific fuel consumption data from the chassis dynamometer tests. This analysis permitted a valid comparison of specific fuel consumption due to the controlled nature of the testing.

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2 SAE SP-63/250. White, John S., "Significant Difference", in Statistics for the Engineer, (Warrendale, PA: Society of Automotive Engineers, Incl. 1980), pp 14-26.

3 Mendenhall, William, Introduction to Probability and Statistics, (Belmont, California, Duxbury Press, 1971)

5.0 RESULTS AND DISCUSSION

5.1 Driveability

Driveability results accumulated from daily driver log sheets, for the propane fleet, are given in Figure 2. In summary 2.5% of the drivers reported difficulty with poor engine starting. Stalling after starting was reported by 1.2% of the drivers. Stalling in traffic was reported by 8.6% of the drivers. Rough idling, hesitation and bucking were reported by 3.7% of the drivers and 6.2% of the respondants reported lack of engine power. These results are comparable to results obtained from drivers operating on regular unleaded gasoline and are a reflection of vehicle type and maintenance and not of fuel type. Although a comparable driveability reporting system was not maintained for the control fleet, fleet operators indicated that driveability and overall performance of the propane powered vehicles was similar to that of gasoline powered vehicles. Generally, the drivers operating the propane vehicles were the same ones who operated the same vehicles before conversion from gasoline to propane.

There were no apparent differences in vehicle maintenance needs or engine durability between propane and gasoline fleet vehicles. Oil analysis at the outset of the program resulted in the frequency of oil changes being increased from 6000 to 12000 km. There was no evidence of propane causing any deterioration of fuel system components.

The MTS fleet manager was pleased with the performance of the propane vehicles. In all cases the propane vehicles were very reliable. Both the drivers and mechanics were generally positive about the use of propane vehicles. Maintenance costs were no higher with propane than with gasoline.

Table 3 presents Winnipeg summer and winter weather data from January, 1980 to August, 1982. This includes the period during which historic fleet data were used (January 1980 to December 1980) as well as the period during the propane fleet data were collected (December 1980 to November 1982). No weather related starting or operating problems were encountered with the propane vehicles during the demonstration period. The vehicles were equipped with block heaters and were stored outside at all times except for periods of maintenance.

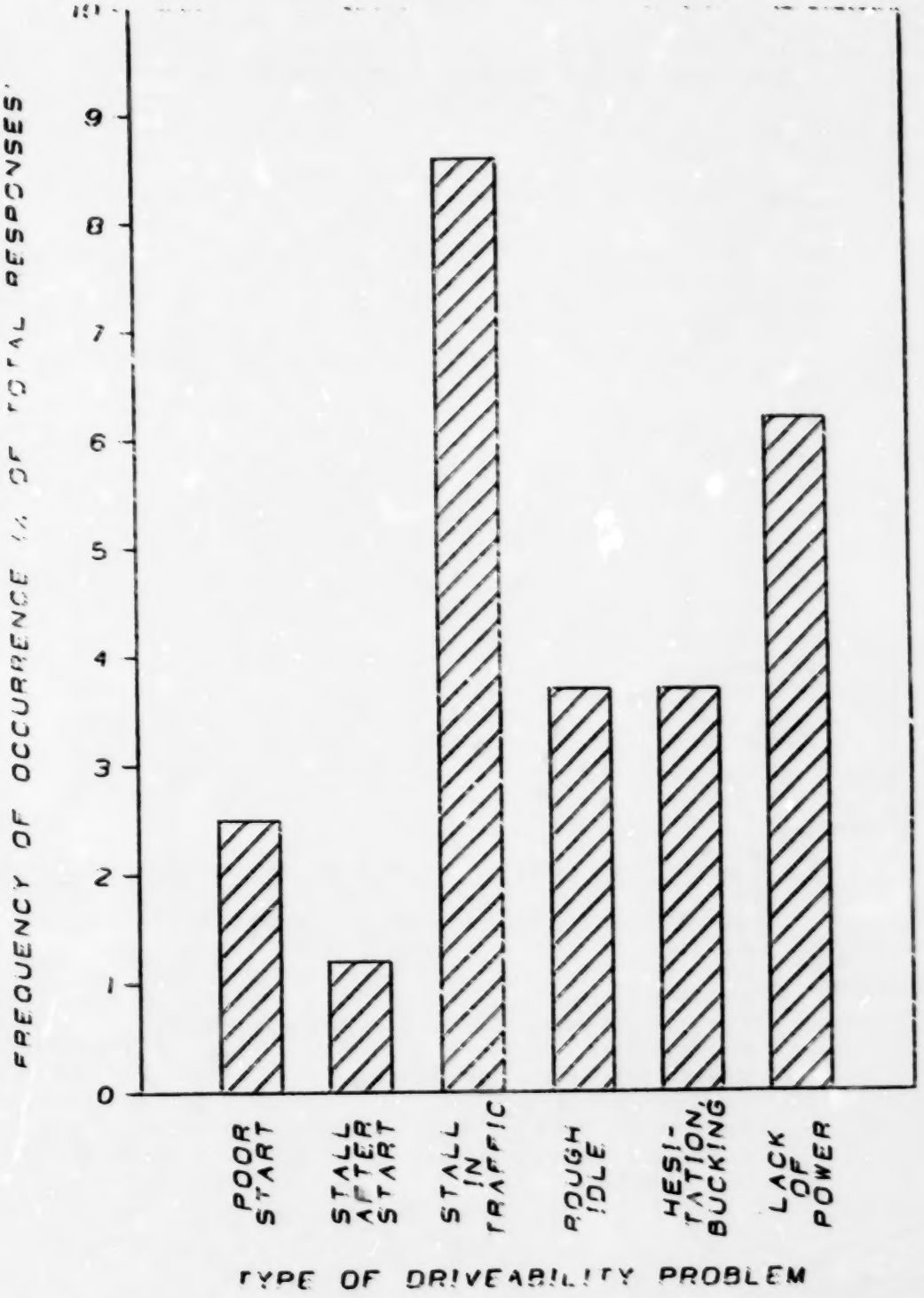

Figure 2. Summary of Driveability Results from Propane Fleet Daily Driver Log Sheets

Table 3: Monthly Summer and Winter Temperatures in Winnipeg

Month/Year	Maximum Mean (°C)	Minimum Mean (°C)	Maximum Extreme (°C)	Minimum Extreme (°C)
12 Months before Conversion				
January 1980	-13.9	-23.6	0.0	-32.3
February 1980	-11.2	-20.5	-1.7	-35.2
March 1980	-4.0	-16.0	8.0	-30.7
June 1980	24.0	9.6	34.4	0.8
July 1980	27.3	13.5	34.8	5.5
August 1980	22.5	11.3	30.7	3.5
Propane Operation				
December 1980	-10.3	-20.6	6.4	-30.3
January 1981	-8.4	-19.7	2.0	-31.8
February 1981	-5.5	-14.7	7.5	-31.0
June 1981	22.3	9.6	27.5	4.7
July 1981	26.8	13.7	34.0	5.6
August 1981	26.6	13.6	18.7	7.8
December 1981	-9.0	-16.8	-3.6	-38.9
January 1982	-19.9	-30.4	-3.6	-38.9
February 1982	-9.5	-19.5	6.0	-34.0
June 1982	20.6	6.5	27.1	-1.0
July 1982	26.0	14.0	31.1	8.4
August 1982	23.0	10.6	29.5	0.7
November 1982	-1.2	-10.3	12.3	-23.8

5.2 Fleet Performance Comparisons

5.2.1 Specific Fuel Consumption Comparison- Paired Historic Fleet Data

Average specific fuel consumption data for the propane fleet vehicles, during the 24 month test period, were compared with historical fuel consumption data for the same vehicles operating on gasoline during the twelve months prior to conversion. Both the historic and propane vehicles were operated exclusively in the Winnipeg area. Statistical testing was based on the difference between fuel consumption values, for each data pair, taken as gasoline consumption less propane consumption. Positive differences indicate a volume saving in fuel consumption using propane. Table 4 summarizes these comparisons. Vehicle types may be determined by referring to Tables 1 and 2.

Table 4. Mean Fuel Consumption of the Propane Fleet Vehicles Compared With Mean Fuel Consumption of the Same Vehicles Operated on Gasoline Prior to Conversion

Vehicle Type (See Tables 1&2)	Specific Fuel Consumption (L/100 km)		
	Gasoline	Propane	Difference
1	17.88	22.55	-4.67
2	14.42	17.12	-2.70
3	26.09	22.46	3.63
4	22.93	20.57	2.36
5	20.21	19.26	0.95
6	22.42	28.14	-5.72
7	25.92	19.56	6.36
8	32.59	23.49	9.10
9	17.74	31.00	-13.26
10	21.95	28.40	-6.45
11	46.03	44.11	1.92
12	21.85	33.15	-11.30
13	22.70	41.20	-18.50
14	32.20	28.79	3.41
15	49.53	52.58	-3.05
16	17.93	18.34	-0.41
17	21.05	24.70	-3.65
18	20.75	23.63	-2.88
19	13.86	21.85	-7.99
20	29.30	28.10	1.20
21	23.76	24.06	-0.30
22	41.72	46.84	-5.12
23	43.48	47.06	-3.58
24	100.23	68.03	32.20
25	102.10	106.35	-4.25

$t_{90,24} = 1.71$

$t_{calc} = 0.71$

A two-tailed paired difference significance test (Appendix II) performed on the data yielded a 't' value of -0.71. At the 90% confidence level, for the mean propane consumption to be significantly different than the mean gasoline consumption, the calculated 't' value must fall outside the range of -1.71 to +1.71. Consequently, the results reported in Table 4 indicate no significant difference in mean specific fuel consumption between the two paired fleets.

The above specific fuel consumption data were converted to specific energy consumption by using gross heats of combustion, determined using an oxygen bomb calorimeter. Gasoline has a gross heat of combustion of 33.8 MJ/L compared to 27.1 MJ/L for propane.

A one-tailed paired difference significance test performed on the specific energy consumption data (Table 5), yielded a 't' value of 2.27 compared to the required minimum value of 1.32 for significance at the 90% confidence level. These results indicate that the propane vehicles consumed significantly less energy than the gasoline vehicles. Consequently, the results indicate that propane is a more energy efficient fuel than gasoline. A 90% confidence level for the difference between energy consumption ranged from 65.1 to 245.1 MJ/100 km.

5.2.2 Specific Fuel Consumption Comparison - Propane and Gasoline Control Fleet

Average fuel consumption data for the propane fleet was compared with data from the control fleet. Only a total of 15 pairs of matched vehicles (Table 1) were used for this comparison. The remaining vehicles in the two fleets could not be matched and therefore, were not valid for inclusion in the statistical analysis. Statistical analysis was based on the average difference between specific fuel consumption for each data pair, taken as the consumption of gasoline less the consumption of propane. Positive differences would indicate a volume saving in fuel consumption using propane. Tables 6 and 7 present results for specific fuel consumption and specific energy consumption, respectively for both the control and propane fleets.

A two-tailed paired difference significance test performed on the data (Table 6), yielded a 't' value of -2.46. At the 90% confidence level for mean propane consumption to be significantly different than the mean of gasoline consumption, the calculated 't' value must fall outside the range of -1.76 to +1.76. These results indicate that the specific fuel consumption of the propane fleet was significantly greater than that of the gasoline fleet. Part of this difference is due to different operating conditions for the two fleets and may not be representative of performance in similar operating conditions.

Table 5. Mean Energy Consumption of the Propane Fleet Vehicles Compared With Mean Energy Consumption of the Same Vehicles Operated on Gasoline Prior to Conversion

Vehicle Type (See Tables 1&2)	Specific Energy Consumption (MJ/100km)		
	Gasoline	Propane	Difference
1	589.91	611.33	-21.42
2	475.70	464.23	11.46
3	861.07	608.89	252.18
4	756.79	557.68	199.11
5	666.93	522.00	144.93
6	739.86	762.82	-22.96
7	855.36	530.16	325.20
8	1075.60	636.92	438.68
9	585.49	840.52	-255.03
10	724.25	769.79	-45.54
11	1519.09	1195.74	323.35
12	720.95	898.70	-177.75
13	748.97	1116.80	-367.83
14	1062.57	780.39	282.18
15	1634.33	1425.50	208.83
16	591.62	497.12	94.50
17	694.65	669.62	25.03
18	684.75	640.64	44.11
19	457.38	592.22	-134.84
20	966.83	761.66	205.17
21	784.01	652.19	131.82
22	1376.60	1269.91	106.69
23	1434.94	1275.85	159.09
24	3307.56	1844.21	1463.35
25	3369.30	2883.15	486.15

$t_{90,24} = 1.32$

$t_{calc} = 2.27$

Table 6. Mean Specific Fuel Consumption of the 15 Matched Fleet Vehicles in the Propane and Control Fleets

Vehicle Type (See Table 1)	Specific Fuel Consumption (L/100 km)		
	Gasoline	Propane	Difference
1	17.21	22.55	-5.34
2	15.82	17.21	-1.91
3	28.88	22.46	6.42
4,5	18.39	19.91	-1.52
6	17.70	28.14	-10.44
7	12.39	19.56	-7.17
8	20.03	23.49	-3.46
9	33.28	31.00	2.28
10	21.32	28.40	-7.08
11,12	32.22	38.63	-6.41
13	22.76	41.20	-18.44
14	36.82	28.79	8.03
15	39.53	52.58	-13.05

$t_{90,14} = 1.76$

$t_{calc} = 2.46$

Table 7. Mean Specific Energy Consumption Comparison of the 15 Matched Fleet Vehicles in the Propane and Control Fleets

Vehicle Type (See Table 1)	Specific Energy Consumption (MJ/100 km)		
	Gasoline	Propane	Difference
1	568.0	611.3	-43.3
2	521.9	480.5	41.4
3	953.0	608.9	344.1
4,5	606.9	539.8	67.1
6	584.0	762.8	-178.8
7	408.9	530.2	-121.3
8	661.0	636.9	24.1
9	1098.1	840.5	257.6
10	703.7	769.8	-66.1
11,12	1063.3	1047.2	16.1
13	751.1	1116.8	-365.7
14	1215.2	780.4	434.8
15	1304.6	1425.5	-120.9

$t_{90,14} = 1.34$

$t_{calc} = 0.47$

Converting the fuel consumption data into specific energy consumption (Table 7), and performing a one-tailed significance test, resulted in a 't' value of +0.47, compared to the required minimum value of 1.34 for significance of the 90% confidence level. This indicated that there was no significant difference in specific energy consumption of the propane and control fleets.

These results contradict the results obtained using historic fleet data. This is to be expected as the control fleet was operated in rural areas while the propane fleet was operated in urban areas. This inconsistency in test procedure was as a result of the unavailability of propane outside Winnipeg during the demonstration period.

During the initial test period fuel consumption data were analyzed using simple regression analyses. The linear regressions of specific fuel consumption as a function of vehicle mass were compared for both the control fleet and the propane fleet. Although these analyses, in some cases, produced significant coefficients of linear regression, the wide scatter of data made this an ineffective method of comparing fuel consumption of the two fleets. Specific fuel consumption is dependent on the aerodynamic configurations and many other variables in addition to vehicle mass. None of the regression comparisons are included in this report.

5.3 Chassis Dynamometer Tests

Table 8 lists the vehicles used in the chassis dynamometer comparison tests.

Results for simulated urban driving at 48 km/h are reported in Table 9. Using a one-tailed paired significance test, the specific fuel consumption when operating on propane was significantly greater (90% confidence level) than when operating on gasoline. This difference was equivalent to a 22.4% increase in fuel consumption if propane is used in place of gasoline.

In simulated highway driving at 88 km/h (Table 10) the specific fuel consumption was, once again, greater when operated on propane than when operated on gasoline. Average propane consumption was 28.2% greater than gasoline consumption.

At the time of the chassis dynamometer testing the cost of propane was 23.5¢/L (0.87¢/MJ) and the cost of gasoline was 43.9¢/L (1.33¢/MJ).

On a cost comparison basis, for the 48 km/h chassis dynamometer tests, propane cost 34.2% less per 100 km than gasoline (see Table 11). For the 88 km/h test propane cost 31.7% less per 100 km than gasoline

(see Table 12). The specific fuel cost results for both the 48 km/h and 88 km/h test are significant at the 90% confidence level.

The chassis dynamometer allowed a high degree of standardization to be achieved by the elimination of uncontrolled variables. The controlled and reproducible conditions allowed the two fuels to be more accurately compared than in actual road tests. The results show that there is an economic advantage for a fleet operator to use propane.

Table 8. Description of Test Vehicles

Vehicle Type	Year	Model	Test Vehicle Mass(kg)	Engine Displacement (L)	Number of Cylinders	Transmissions
A	1979	Concord Sedan	1430	3.80	6	3 Speed Automatic
B	1979	Ford Van	1723	4.92	6	3 Speed Standard
C	1979	Ford Pick up	1773	4.92	6	3 Speed Automatic
D	1979	Chevrolet Van	1866	5.74	8	3 Speed Automatic
E	1978	Dodge Van	2394	5.21	8	3 Speed Automatic
F	1979	Chevrolet Step Van	2812	5.76	8	4 Speed Standard

Table 9. Chassis Dynamometer Results for 48 km/h (Simulated Urban Driving)

Vehicle Type (See Table 7)	Specific Fuel Consumption (L/100km)			Power Output (kw)
	Gasoline	Propane	Difference	
A	18.23	27.87	- 9.64	25.86
B	23.11	32.28	- 9.17	30.59
C	28.93	43.05	-14.12	41.03
D	43.71	44.75	- 1.04	35.06
E	52.14	52.68	- 0.54	33.57
F	50.98	65.14	-14.16	58.19
	217.10	265.77	-48.67	

$t_{90,5} = 1.48$
$t_{calc} = 3.28$

Table 10. Chassis Dynamometer Results for 88 km/h (Simulated Highway Driving)

Vehicle Type (See Table 7)	Specific Fuel Consumption (L/100km)			Power Output (kw)
	Gasoline	Propane	Difference	
A	7.07	12.46	- 5.39	28.35
B	12.12	15.43	- 3.31	29.84
C	8.87	11.90	- 3.03	25.36
D	13.72	12.46	+ 1.26	26.60
E	26.03	28.13	- 2.10	27.87
F	29.15	43.90	-14.75	51.47
	96.96	124.28	-27.32	

$t_{90,5} = 1.48$
$t_{calc} = 5.45$

Table 11. Specific Fuel Costs for 48 km/h Chassis Dynamometer Test

Vehicle Type (See Table 7)	Specific Fuel Cost ($/100 km)		Difference
	Gasoline	Propane	
A	8.00	6.55	1.45
B	10.14	7.59	2.55
C	12.70	10.12	2.58
D	19.19	10.52	8.67
E	22.89	12.88	10.01
F	22.38	15.31	7.07
	95.30	62.5	32.33

$t_{90,5} = 1.48$
$t_{calc} = 2.04$

Table 12. Specific Fuel Cost for 88 km/h Chassis Dynamometer Test

Vehicle Type (See Table 7)	Specific Fuel Cost ($/100 km)		Difference
	Gasoline	Propane	
A	3.10	2.93	0.17
B	5.32	3.63	1.69
C	3.89	2.80	1.09
D	6.02	2.93	3.09
E	11.63	6.61	5.02
F	12.80	10.32	2.48
	42.6	29.21	13.54

$t_{90,5} = 1.48$
$t_{calc} = 3.25$

6.0 SUMMARY AND CONCLUSIONS

The following conclusions may be drawn as a result of 24 months of fleet testing during which time the propane and control fleets travelled a cumulative distance of 1.75 million km.

6.1 Based on a summary of fleet driver daily log sheets, no driveability or overall vehicle performance problems were apparent on the propane vehicles. Cold weather starting was no more problematical with propane fuel systems than with gasoline since block heaters were routinely used.

6.2 Because of propane availability and logistic reasons the propane fleet was operated in urban areas while the gasoline control fleet was operated in rural areas. Although this yielded suitable driveability comparison results, the two fleets could not be used for valid fuel consumption comparisons.

6.3 Comparison of the specific fuel consumption of the 25 propane fleet vehicles to the specific fuel consumption of the same vehicles, operating under similar conditions for the 12 month period prior to conversion to propane, permitted valid fleet fuel consumption comparisons. Results of this comparison indicated no difference in specific fuel consumption for the two fleets. The specific energy consumption of similar vehicles was, however, significantly lower (90% confidence level) when operated on propane than when operated on gasoline. The difference in specific energy consumption varied from 65.1 to 245.1 MJ/100 km.

6.4 Chassis dynamometer tests on six pairs of vehicles operating on propane and gasoline, permitted scientifically valid vehicle performance comparisons in controlled conditions:

(a) In simulated urban driving at 48 km/h the specific fuel consumption of the same vehicles was significantly higher (90% confidence level) when operated on propane than when operated on gasoline. Similarly, in simulated highway driving conditions at 88 km/h, the specific fuel consumption of the same vehicles was significantly higher (90% confidence level) when operating on propane than when operated on gasoline.

(b) On a cost basis of 23.5¢/L for propane and 43.9¢/L for gasoline the cost per 100 km for propane was significantly lower (90% confidence level) than for gasoline at both the 48 km/h and 88 km/h. Average cost savings were 34% in urban driving and 32% in highway driving.

6.5 There was no evidence of propane causing any deterioration of fuel system components. There was also no apparent differences in vehicle maintenance needs or engine durability between propane and gasoline fleet vehicles.

6.6 This demonstration illustrated that there are definite advantages to the use of propane as an alternate fuel to gasoline. Although on the average, the propane-powered vehicles consumed more fuel than their gasoline counterparts, the fuel cost difference gave propane a distinct economic advantage.

6.7 The MTS fleet manager was pleased with the performance of the propane vehicles. The propane vehicles were reliable and maintenance costs were no worse with propane compared to gasoline. This project has proved that the use of propane fuel is feasible and economically advantageous for commercial fleet vehicles.

7.0 RECOMMENDATIONS

7.1 For future fleet tests it should be ensured that the test fleet and control fleet contain similar paired vehicles and operate in similar driving conditions. Due to the nature of fleet tests, however, interpretation of results obtained from actual fleet operation should concentrate on differences in driveability and maintenance.

7.2 The use of chassis and engine dynamometers should be considered essential in future fleet tests in comparing vehicles operating on different fuels. Such techniques permit valid comparisons in controlled conditions, by eliminating many of the uncontrolled variables inherent in actual field operation.

7.3 Fleet operators should consider propane as an attractive alternative to gasoline in future vehicle and bulk fuel purchases.

APPENDIX I

Statistical Analyses of Fuel and Energy Consumption Data

(a) Statistical Methods

Propane and gasoline fleet fuel and energy consumption data were analyzed with paired difference significance tests using student's t-distribution. In performing these analyses it was assumed that the sample standard deviation was a good estimate of the population standard deviation and that the population was normally distributed. The null hypothesis (Ho) in each case was that there was no difference between the mean consumption of gasoline and the mean consumption of propane. Depending on the specific data, one-tailed or two-tailed tests were performed.

(b) Analysis of Fleet Results

(1) Analysis of Data in Table 4, page 17 (two-tailed t test)

di	No. of Vehicle Pairs (n)	Standard Deviation (Sd)	t calculated	$t_{90,24}$
-32.69	25	9.25	-.71	$\pm$ 1.71
Ho is not rejected				

(2) Analysis of Data in Table 5, page 19 (one-tailed test)

di	No. of Vehicle Pairs (n)	Standard Deviation (Sd)	t calculated	$t_{90,24}$
2098.1	25	9.25	2.27	$\pm$1.32
Ho is rejected at the 90% confidence level				

(3) Analysis of Data in Table 6, page 20 (two-tailed t test)

di	No. of Vehicle Pairs (n)	Standard Deviation (Sd)	t calculated	$t_{90,14}$
-66	15	6.93	-2.46	$\pm$ 1.76
Ho is rejected at the 90% confidence level				

(4) Analysis of Data in Table 7, page 21 (one-tailed test)

di	No. of Vehicle Pairs (n)	Standard Deviation (Sd)	t calculated	$t_{90,14}$
372.2	15	203.1	0.47	1.34
Ho is not rejected				

(5) Analysis of Data in Table 9, page 25 (one-tailed test)

di	No. of Vehicle Pairs (n)	Standard Deviation (Sd)	t calculated	$t_{90,5}$
-48.6	6	6.08	3.28	1.48
Ho is rejected at the 90% confidence level				

(6) Analysis of Data in Table 10, page 25 (one-tailed test)

di	No. of Vehicle Pairs (n)	Standard Deviation (Sd)	t calculated	$t_{90,5}$
-29.84	6	5.45	5.45	1.48
Ho is rejected at the 90% confidence level				

(7) Analysis of Data in Table 11, page 26 (one-tailed test)

di	No. of Vehicle Pairs (n)	Standard Deviation (Sd)	t calculated	$t_{90,5}$
32.33	6	3..64	2.04	1.48
Ho is rejected at the 90% confidence level				

(8) Analysis of Data in Table 12, page 26 (one-tailed test)

di	No. of Vehicle Pairs (n)	Standard Deviation (Sd)	t calculated	$t_{90,5}$
13.35	6	1.70	3.25	1.48
Ho is rejected at the 90% confidence level				

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